UNITED STATES DISTRICT COURT
FOR THE NORTHERN DISTRICT OF CALIFORNIA
SAN FRANCISCO DIVISION

COREPHOTONICS, LTD. Plaintiff, vs. APPLE INC. Defendant.	Case No. 3:17-cv-06457-JD (Lead Case) Case No. 3:18-cv-02555-JD

DECLARATION OF JOHN C. HART REGARDING CLAIM CONSTRUCTION OF CERTAIN TERMS OF U.S. PATENT NOS. 9,185,291 AND 9,568,712

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I, John C. Hart, declare and state as follows:

I. INTRODUCTION

1. I have been retained as an expert in the above-captioned case by Corephotonics, Ltd. ("Corephotonics"). I understand that Corephotonics has asserted two patents in this case: U.S. Patent Nos. 9,185,291 (the "'291 patent") and 9,568,712 (the "'712 patent") (together, the "Asserted Patents").

2. I have been asked to consider and opine on claim constructions for certain disputed claims terms in these patents, which I set forth and address in separate sections below for each term.

3. In forming my opinions, I have reviewed, considered, and/or had access to the patent specifications and claims, their prosecution histories and intrinsic record, the parties' proposed claim constructions, and the extrinsic evidence cited by the parties in connection with those proposed constructions. I have also relied on my professional and academic experience in the field, including my over 30 years of study and research of image acquisition and processing systems.

4. I am being compensated for my work in this matter at the rate of $575 per hour. I am also being reimbursed for reasonable and customary expenses associated with my work and testimony in this investigation. My compensation is not contingent on the outcome of this matter or the substance of my testimony.

II. QUALIFICATIONS

5. My qualifications for forming the opinions set forth in this Declaration are summarized here and explained in more detail in my curriculum vitae, which is attached as Exhibit A.

6. As indicated in my Curriculum Vitae, I am a tenured full Professor of Computer Science in the Department of Computer Science at the University of Illinois at Urbana-Champaign. As an educator for the past three decades, I have taught courses in computer graphics and related areas

to thousands of students. I also strive to provide opportunities for the general public to learn more about computing. For example, in 1999 I oversaw the production of the documentary "The Story of Computer Graphics." I also teach an open course on data visualization on Coursera that has reached over 360,000 learners worldwide since 2016.

7. In 2016, I redesigned the online offering of the MCS degree program to make it more flexible and affordable for students that could not afford to leave their job to pursue a degree fulltime. Under my leadership, this degree program quickly grew to the second largest graduate program offered by the University of Illinois at Urbana-Champaign, and contributed significantly to the campus-wide proportion of underrepresented minorities enrolled in the institution. The tech company C3.ai found this online degree so desirable, it pays its employee's tuition and upon completion, gives them a bonus, a raise and stock options.

8. I am also the Director of Professional Education of the University of Illinois at Urbana-Champaign, and oversee and coordinate UIUC's offerings that offer educational opportunities beyond degrees, including certificate programs and open education that serve a broader segment of the general public with opportunities for professional advancement, career transition and/or personal development.

9. I have been researching computer graphics since 1987, with over a hundred papers, videos, patents and other contributions to computer graphics including photographic imaging systems. My work in computer graphics has been funded by Adobe, Intel, Microsoft, Nokia and Nvidia as well as the National Science Foundation (NSF) and the Defense Advanced Research Projects Agency (DARPA).

10. I am an internationally recognized leader in the field of computer graphics. From 2002-08 I was the Editor-in-Chief of the top journal in computer graphics, the Association for Computing

Machinery (ACM) Transactions on Computer Graphics. From 1994-1999 I served on the executive committee of the main organization of computer graphics practitioners, the ACM Special Interest Group on Computer Graphics and Interactive Techniques (SIGGRAPH). I continue to oversee the peer review of major papers in the field through service as chair and member of various paper review committees. I am also a founding member of the editorial board of ACM Books, and served as its first area editor for computer graphics.

11. This report is on the subject of photographic imaging systems. I have worked on a variety of methods and systems for the fusion of photographs. For example, in 2008 I was granted U.S. Patent No. 7,365,744, titled "Method and Systems for Image Modification," on techniques for learning a surface appearance from one photograph and realistically applying it to a different surface in another photograph.

12. My professional and academic work has often included the use of image fusion techniques. For example, in 2013, I was funded by the National Science Foundation's Advanced Digitization of Biodiversity Collections to design and deliver an imaging infrastructure to scan the nation's entomological collections of insect drawers. This project, available at invertnet.org, required the fusion of 51,791 photographic images of small portions of insect drawers, vials and slides to make the collections available via the Internet as high-resolution zoomable composite images. This effort included the design and deployment of a custom robotic photographic imaging system, designed specifically to capture and fuse numerous photographs of each specimen drawer.

13. More recently, I worked along with Facebook's Oculus group on the challenge of displaying readable text on the video screen of a VR headset, given the challenges of its lensing, wide field of view and varying point of view. This paper, "Real-Time Analytic Antialiased Text

for 3D Environments," was selected as one of the best papers at the 2019 High-Performance Graphics Conference in Strasbourg France in July.

III. LEVEL OF ORDINARY SKILL IN THE ART

14. In my opinion, a person of ordinary skill in the relevant art ("POSITA") for the '291 patent would be a person with a bachelor's degree or equivalent in computer engineering, electrical engineering, or a related field, with approximately 2–3 years of experience in imaging systems. A person with less education but more relevant practical experience, or vice versa, may also meet this standard.

15. In my opinion, a POSITA for the '712 patent would be a person with a bachelor's approximately 2–3 years of experience in imaging systems or equivalent in computer engineering, optical engineering, or related field, with at least 2 years of experience working with optical designs.

16. I further note that I am at least a POSITA and that for 30 years I have worked with colleagues who are POSITAs. Thus, I am well qualified to give technical opinions from the perspective of a POSITA for the Asserted Patents.

IV. CLAIM CONSTRUCTION PRINCIPLES

17. I understand that a claim construction inquiry begins and ends in all cases with the actual words of the claim. Thus, quite apart from the written description and the prosecution history, the claims themselves provide substantial guidance as to the meaning of particular terms. I further understand that to begin with, the context in which a term is used in the asserted claim can be highly instructive. The patent specification can also shed light on the meaning of claim terms.

18. I understand that when conducting a claim construction inquiry, district courts are not (and should not be) required to construe every limitation present in a patent's asserted claims. Simply

put, claim construction is not an obligatory exercise in redundancy. I further understand that where a term is used in accordance with its plain meaning, the court should not re-characterize it using different language.

19. I understand that there is a "heavy presumption" that claim terms carry their full ordinary and customary meaning, unless the accused infringer can show the patentee expressly relinquished claim scope. The ordinary and customary meaning of a claim term is the meaning that the term would have to a person of ordinary skill in the art in question at the time of the invention. Thus, the task of comprehending the claims often involves little more than the application of the widely accepted meaning of commonly understood words.

20. I understand that without clear and unambiguous disclaimer, courts do not import limitations into claims from examples or embodiments appearing only in a patent's written description, even when a specification describes very specific embodiments of the invention or even only a single embodiment. Similarly, statements during patent prosecution do not limit the claims unless the statement is a clear and unambiguous disavowal of claim scope.

21. I understand that Defendant bears the burden of proving that a claim is indefinite by clear and convincing evidence. I understand that a patent is invalid for indefiniteness if its claims, read in light of the specification delineating the patent, and the prosecution history, fail to inform, with reasonable certainty, those skilled in the art about the scope of the invention.

V. OVERVIEW OF THE ASSERTED PATENTS[1]

A. The '291 Patent

22. The '291 patent is directed to thin dual-lens digital cameras with optical zoom, which operate in both video and still mode. '291 pat., 3:14-24. The '291 patent generally describes technology that uses image fusion to combine the images from the two cameras with different fields of view ("FOV")—which the patent refers to with coined terms "Wide" and "Tele"—for still pictures, but does not use image fusion for video. In particular, the '291 patent discloses processing for the "still camera mode," which includes capturing synchronous images from both the Wide and Tele cameras, and fusing the Wide and Tele images "to achieve optical zoom." *Id.* at 7:25-39. In continuous video mode, the '291 patent discloses digitally zooming either the Wide camera image or Tele camera image, depending on the level of zoom. For example, when zooming in, the video output will be from the Wide camera, up to a point at which the output will switch to being from the Tele camera. *Id.*, 10:30-34. Exemplary claim 1 of the '291 patent provides as follows:

> **1.** A zoom digital camera comprising:
>
> **a)** a Wide imaging section that includes a fixed focal length Wide lens with a Wide field of view (FOV), a Wide sensor and a Wide image signal processor (ISP), the Wide imaging section operative to provide Wide image data of an object or scene;
>
> **b)** a Tele imaging section that includes a fixed focal length Tele lens with a Tele FOV that is narrower than the Wide FOV, a Tele sensor and a Tele ISP, the Tele imaging section operative to provide Tele image data of the object or scene; and
>
> **c)** a camera controller operatively coupled to the Wide and Tele imaging sections, the camera controller configured to combine in still mode at least some of the Wide and Tele image data to provide a fused output image of the object or scene from a particular point of view and to provide without

[1] My description of the overview of the Asserted Patents substantially follows and adopts the description set forth in Corephotonics's first opening claim construction brief, which was filed November 21, 2018.

> fusion continuous zoom video mode output images of the object or scene, each output image having a respective output resolution;
>
> wherein the video output images are provided with a smooth transition when switching between a lower zoom factor (ZF) value and a higher ZF value or vice versa, wherein at the lower ZF value the output resolution is determined by the Wide sensor, and wherein at the higher ZF value the output resolution is determined by the Tele sensor.

23. Fig. 2 of the '291 patent illustrates the issues that arise due to the different fields of view of the Wide camera and the Tele camera.

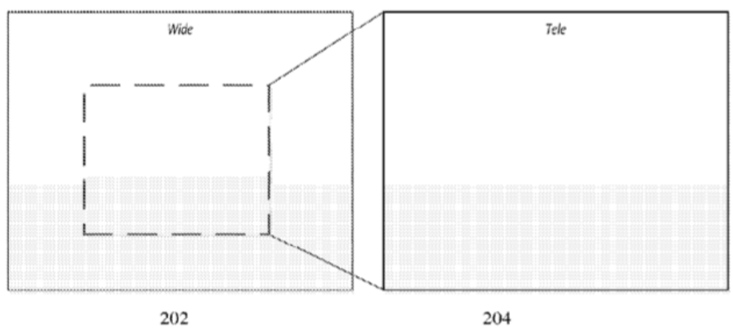

FIG. 2

24. As Fig. 2 shows, because the Tele camera has a narrower field of view than the Wide camera, the Tele camera generates images that overlap within a subset portion of the wider field of view of the image generated by the Wide camera.

25. The '291 patent discloses the acquisition of single zoom images that combine image data from the Tele and Wide cameras in the still camera mode. *Id.*, 9:15-43. The Wide and Tele cameras

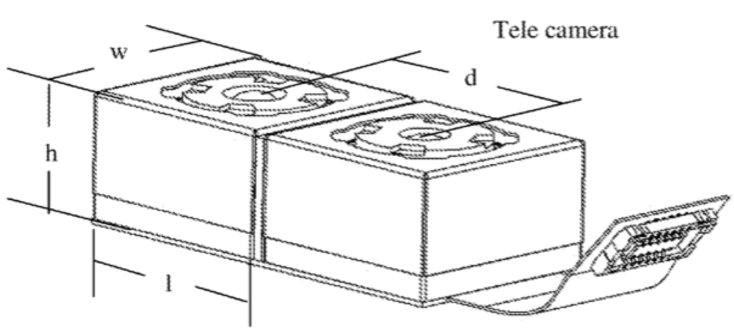

FIG. 1B

will be at separate positions on a device, as shown in Fig. 1B of the ’291 patent. Because the cameras are at different spatial positions, the Wide and Tele cameras take images seen from different points of view (POV). *Id.*, 4:60-5:2. The patent further discloses how the camera controller can be configured in still mode to provide a fused output image from the point of view of the Tele camera at higher levels of zoom, a fused output image from the point of view of the Wide camera at lower levels of zoom, and transition between those while zooming in and out. *Id.*, 9:52-10:10.

26. During video zoom, *i.e.*, when the camera is being zoomed in and out while a video is being displayed, the zoom operation switches between Wide and Tele cameras. *Id.*, 10:56-11:5. The ’291 patent teaches that while displaying video, if the zoom operation switches “between sub-cameras or points of view, a user will normally see a ‘jump’ (discontinuous change).” *Id.*, 10:13-17. The ’291 patent addresses this problem by providing a video zoom with a “smooth transition” during this switchover, which the ’291 patent defines “a transition between cameras or POVs that minimizes the jump effect.” *Id.*, 10:17-19. The ’291 patent goes on to teach methods for achieving a smooth transition in video zoom mode, including position matching, to address the different spatial perspectives and viewing angles of each camera, as well as matching scale, brightness, and color. *Id.*, 10:19-27 *et seq*.

27. The ’291 patent further discloses compact lenses that achieve optical zoom with a small total track length (TTL) with a small “thickness/focal length” ratio. The embodiments disclosed in the ’291 patent provide a TTL less than EFL, like those disclosed in the ’712 patent. *See* ’291 pat., 12:13-20 *et seq.*, Figs. 8, 9.

B. The ’712 Patent

28. The ’712 patent is directed to providing a miniature telephoto lens assembly usable in mobile devices, such as smartphones. *See, e.g.*, ’712 pat., 1:18-22. In particular, the ’712 patent is directed to providing a compact lens assembly with a small total track length (TTL) and small ratio of TTL to the effective focal length (EFL) of the lens assembly. *Id.*, 1:25-41, 1:62-2:2. The total track length (TTL) determines the physical length of the camera, so a small TTL results in a smaller, more compact camera. The effective focal length (EFL) determines how well the camera performs at capturing images of small or distant objects. A lens with a greater EFL is able to capture images of such objects with greater detail. All claims of the Asserted Patents require that the TTL be smaller than the EFL, *i.e.*, that the TTL to EFL ratio be smaller than 1.0. This provides a telephoto lens assembly that can be utilized in a thin dual camera optical zoom system suitable for smartphones. The ’712 patent claims relate to different lens parameters that yield a system with a TTL smaller than the EFL, along with other optical properties. An example is Claim 15 of the ’712 patent, highlighting the one claim term in dispute:

> 15. A lens assembly, comprising: a plurality of refractive lens elements arranged along an optical axis, wherein the lens assembly has an effective focal length (EFL) and a total track length (TTL) smaller than the effective focal length (EFL), the plurality of refractive lens elements comprising, in order from an object plane to an image plane along the optical axis, a first lens element having positive optical power, a pair of second and third lens elements having together a negative optical power, and a combination of fourth and fifth lens elements, the fourth lens element separated from the third lens element by an air gap greater than TTL/5.

29. The following drawing is an exemplary embodiment, which shows exemplary shapes of lenses and gap distances. '712 pat., Fig. 1A.

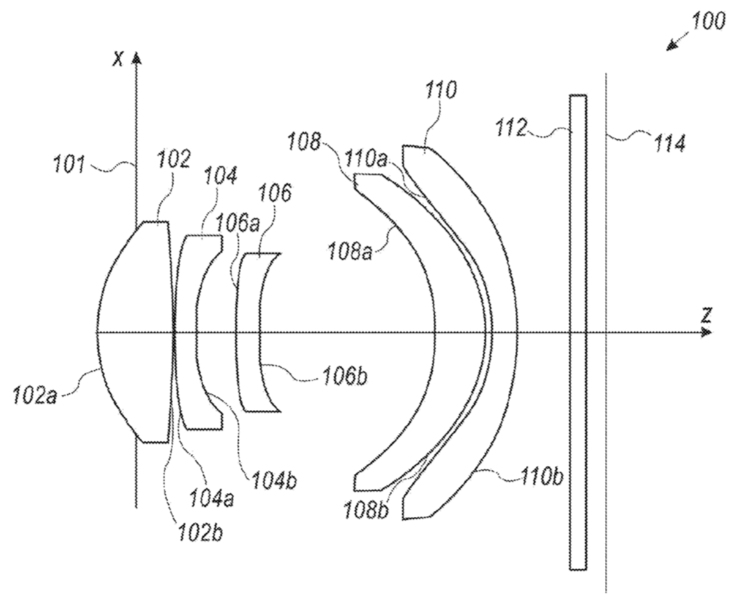

FIG. 1A

VI. AGREED TERMS

30. I understand that Corephotonics and Apple have agreed to the constructions below.

Asserted Claims	Term or Phrase	Agreed Construction
'291 patent cl. 6 '712 patent, cls. 1, 15, 19	"total track length (TTL)" / "total length (TTL)" / "(TTL)"	the length of the optical axis spacing between the object-side surface of the first lens element and one of: an electronic sensor, film, and an image plane corresponding to either the electronic sensor or a film sensor
'712 patent, cl. 15	"optical power"	refractive power
'712 patent, cls. 1, 15	"effective focal length (EFL)" / "EFL"	the focal length of a lens assembly
'291 patent, cls. 1, 12	"smooth transition"	a transition between cameras or points of view that minimizes the jump effect

VII. DISPUTED CLAIM TERMS

A. "Wide" (*'291 patent, claims 1, 2, 4, 5, 10, 12, 13*)

Corephotonics' Proposed Construction	Apple's Proposed Construction
"Wide" refers to one of a pair of imaging sections with a wider field of view	No construction necessary. If the Court determines that construction is necessary, Apple would propose that "Wide" means "wide-angle," or, alternatively, "wide-angle, characterized by an effective focal length (EFL) shorter than normal and field of view (FOV) wider than normal."

31. In my opinion, the "Wide" and "Tele" terms which the parties dispute are used by the patentee to refer to and denote two separate groups of components as well as individual components in those two separate groups. This is made clear in both the specification and the patent claims themselves, in addition to the fact that the words "Wide" and "Tele" were capitalized by the patentees to identify them as proper adjectives instead of generic terms. For example, the '291 patent specifically states, in the context of the prior art, that the descriptors "Wide" and "Tele" refer to ***sensors*** which are used to produce images with relatively differing fields of view and output resolutions. '291 patent, at 2:10-14.

32. It is also my opinion that "Wide" and "Tele" were used by the patentee to refer to a relative relationship between the imaging sections, and that patentee did not use these terms to refer to the configuration of either imaging section in absolute terms. It is common in the art with multi-aperture imaging systems to describe their respective imaging "sections" as differing ***relative*** to one another rather than in absolute terms with respect to fields of view or total-track-length-to-focal-length (TTL/EFL) ratios. This is shown in the prior art cited by the '291 patent. For example, U.S. Patent App. Pub. 2010/0277619 to Scarff ("Scarff"), which is cited at 2:3 of the '291 patent, discusses a dual-aperture imaging system like so:

> The camera 10 may include a first lens 12 having a **relatively-shorter focal length** and a first sensor 14 that are located proximate to and substantially aligned with a second lens 16 having a **relatively-longer focal length** and a second sensor 18. By having the combined first lens and first sensor aligned with the combined second lens and second sensor, the sensors can each obtain an image of substantially the same subject. Of course, due to the different focal lengths of the lenses 12 and 16, the first sensor 14 will obtain an image of the subject with a **relatively-wider field of view (FOV)** as compared to **the relatively-narrower FOV** of the image obtained by the second sensor 18.

Scarff, at [0012].

33. The ’291 patent’s specification discussion evinces a similar approach as in Scarff. The specification consistently uses the words “Wide” and “Tele” as adjective denoting membership in or relationship to a specific groups of components, and not as a limiter necessarily imposing some sort of “wide angle” or “telephoto” requirement. *See, e.g.*, ’291 patent, at 4:24-34. Likewise, the claims of the ’291 patent also use “Wide” and “Tele” in this manner. Claim 1 of the ‘291 patent recites as follows:

> 1. A zoom digital camera comprising:
> a) a Wide imaging section that includes a fixed focal length Wide lens with a Wide field of view (FOV), a Wide sensor and a Wide image signal processor (ISP), the Wide imaging section operative to provide Wide image data of an object or scene;
> b) a Tele imaging section that includes a fixed focal length Tele lens with a Tele FOV that is narrower than the Wide FOV, a Tele sensor and a Tele ISP, the Tele imaging section operative to provide Tele image data of the object or scene; and
> c) a camera controller operatively coupled to the Wide and Tele imaging sections, the camera controller configured to combine in still mode at least some of the Wide and Tele image data to provide a fused output image of the object or scene from a particular point of view and to provide without fusion continuous zoom video mode output images of the object or scene, each output image having a respective output resolution;
> wherein the video output images are provided with a smooth transition when switching between a lower zoom factor (ZF) value and a higher ZF value or vice versa, wherein at the lower ZF value the output resolution is determined by the Wide sensor, and wherein at the higher ZF value the output resolution is determined by the Tele sensor.

34. As shown above, claim 1 uses “Wide” and “Tele” as words to denote a relationship to two different groups of components, with each group being an “imaging section,” and with each “imaging section” having a “lens” having a FOV that is either narrower or wider than that of the

lens in the other imaging section, a "sensor," and an "image signal processor." In the context of the claims, "Wide" and "Tele" together refer to a pair of imaging sections that differ with respect to the FOVs captured by their lenses.

35. Both of Apple's alternative proposals add a requirement that "Wide" mean "wide-angle." In my opinion, this would result in uncertain claim scope. For example, were "Wide" in the claims substituted with "wide-angle," claim 1 would require, among other things, a "wide-angle sensor" and a "wide-angle image signal processor," both of which are meaningless phrases because neither a "sensor" or "image signal processor" can have a "wide angle" in the sense of having a particular FOV or FOV within a particular range as Apple's second proposal requires.

36. Apple's second alternative proposal adds an additional requirement: "characterized by an effective focal length (EFL) shorter than normal and field of view (FOV) wider than normal." This proposal relies on concepts of a "normal" EFL and a "normal" FOV. It is unclear what Apple means with its references to a "normal" EFL and "normal" FOV. The concepts of "normal" EFL and "normal" FOV do not exist in the art, and would not be apparent to a POSITA.

37. I am aware that Corephotonics has implemented commercial embodiments of its inventions with dual-camera modules having both a wide angle and telephoto lens. I also understand that the claims of a patent are not defined or limited by their commercial embodiments. The claims here use the two terms "Wide" and "Tele" to refer to two-camera systems in which one of the two has a wider field of view than the other, regardless of whether one could be described as "wide-angle" or "telephoto."

B. "Tele" ('291 patent, claims 1, 2, 4, 5, 10, 12, 13)

Corephotonics' Proposed Construction	Apple's Proposed Construction
"Tele" refers to one of a pair of imaging sections with a narrower field of view	telephoto, characterized by a TTL/EFL ratio less than 1. Alternatively, in the event the Court does not adopt that construction, Apple

Corephotonics' Proposed Construction	Apple's Proposed Construction
	would propose that "Tele" means "telephoto, characterized by an effective focal length (EFL) longer than normal and field of view (FOV) narrower than normal."

38. As I explained above for the "Wide" term, "Wide" and "Tele" are terms used by the '291 patent to refer to two separate groups of components, each group being an "imaging section," and each "imaging section" having certain components such as a lens, sensor, and image signal processor. This is why Corephotonics' proposal for "Tele" is correct.

39. Apple's primary proposal for "Tele" imposes a specific structural design (i.e., a TTL/EFL<1 requirement). Like with its arguments for "Wide," Apple's position here would result in absurd claim scope. For example, claim 1 would require a "telephoto [image sensor], characterized by a TTL/EFL ratio less than 1." It would also require a "telephoto [image signal processor], characterized by a TTL/EFL ratio less than 1."

40. Of course, sensors and image signal processors are computer chips which do not have track lengths or focal lengths, and thus it is nonsensical to speak of a sensor or an ISP meeting a specific TTL/EFL ratio requirement.

41. If Apple intends for its proposal to mean that the ***lens*** of the Tele imaging section should have a TTL/EFL>1, that requirement is found in dependent claims. Claim 6 recites: "The camera of claim 1, wherein the Tele lens includes a ratio of total length (TTL)/effective focal length (EFL) smaller than 1." The limitation sought by Apple here already exists in a dependent claim, which I understand may violate the doctrine of claim differentiation for claim construction.

42. Finally, Apple's alternative proposal for "Tele" fails because it relies on undefined concepts of "normal" FOV and "normal" EFL. Apple has not identified any extrinsic evidence of or evidence based any statement or teaching in the intrinsic record as to a "normal" and "normal"

EFL. These are not concepts in the field, and so their use here by Apple makes the proposal unworkable and unhelpful.

C. "fused" / "fusion" (*'291 patent, claims 1, 12, 13*)

Corephotonics' Proposed Construction	Apple's Proposed Construction
Corephotonics proposes that these terms be construed in their full context. See Terms D ("fused output image" / "without fusion …. output images") & E ("fused output image of the object or scene from a particular point of view").	"fused": formed into a composite that includes pixels from the Wide and Tele images. "fusion": forming a composite that includes pixels from the Wide and Tele images.

43. The parties' dispute over the "fused" / "fusion" terms for Term C overlaps with their disputes concerning the broader terms, which in relevant part includes whether "fusion" requires producing a composite image that "includes pixels" from two other images. It is my opinion that resolving the parties' competing proposals for Terms D and E will also resolve, in principal, the dispute for "fused" / "fusion" in Term C.

D. "fused output image" / "without fusion … output images" (*'291 patent, claims 1, 12, 13*)

Corephotonics' Proposed Construction	Apple's Proposed Construction
"fused output image" means "output image including a combination of image information from two images" "without fusion … output images" means "output images not created by combining image information from two images"	"fused output image": a composite output image that includes pixels from the Wide and Tele images. "without fusion . . . output images": output images that do not include a composite image that includes pixels from the Wide and Tele images.

44. Based on the parties' competing proposals, the parties' core dispute over the "fusion" terms (including Terms C, D and E) is whether the concept of fusion requires producing an output image which "includes pixels from" two input images. In my opinion, Apple's position on the "fusion" terms deviates from the context of the '291 patent.

45. First, Apple's proposals improperly narrow the general term "fusion" to a specific type of fusion in which some of the "pixels" of one image are replaced with "pixels" from another image. "Fusion" as used by those skilled in the art and within the '291 patent is not so limited. To use an example from taxonomy, Apple improperly seeks to limit the ***genus*** term "fusion" to one particular ***species*** of fusion. Apple's proposal contradicts the ordinary meaning of "fusion" and the '291 patent's technical teachings. The claims and specification of the '291 patent convey no pixel-inclusion requirement as Apple's proposal would import. "Fusion" simply requires, as Corephotonics proposal conveys, combining information from two images. The concept of "fusion" may include methods that produce "a composite output image that includes pixels" from two images (as was disclosed in the prior art cited by the '291 patent), but a POSITA would not understand fusion to be ***limited*** in that way, and would instead understand fusion to include other methods that produce an "output image including a combination of image information from two images," but may not include any single pixel that could be traced back to precisely one of the two source images.

46. For example, in the field of digital image processing, the concept of "fusion" includes methods for extracting color information (as opposed to actual pixels) from one image and combining this information with another, grayscale, image. This is shown in the prior art of record for the '291 patent. For example, U.S. Patent App. Pub. 2012/0026366 to Golan et al. ("Golan '366") is directed to a method of electronic zoom for an imaging system with multiple cameras having different FOVs. Golan '366 teaches (among other thing) a method of fusion where the color data extracted from a color image (and not the pixels of said image) are used to modify the pixels of another, grayscale image. Golan '366, at [0067]-[0068]. While there may be a correspondence between the output image pixels and the grayscale input image, the output of Golan's fusion

method does not include any pixels from either image. What Golan ’366 teaches is a way of taking the color information from a color image using it to color-in the pixels of a grayscale image. This, too, is “fusion” within the meaning of the art and the general knowledge of a POSITA, but does not involve replacing pixels from one image with pixels from another image or involve a requirement that pixels from both images always be included in the output image.

47. Similarly, consider WO2015/015383, “Thin Multi-Aperture Imaging System with Auto-Focus and Methods for Using Same” (“Shabtay ’383”) and assigned to Shabtay, Cohen, Goldenberg, and Gigushinski—the same named inventors as on the ’291 patent.[2] Shabtay ’383 teaches several techniques described therein as “fusion,” but which would be excluded by Apple’s proposal. For example, Shabtay ’383 teaches a technique of taking two images, each with a given resolution, and then feeding those images into an “image fusion algorithm” to produce an image with a greater resolution than either of the input images. *See* Shabtay ’383 at 9:9-18. Here, the resulting output image from Shabtay ’383’s image fusion algorithm contains no “pixels” at all from either image. Rather, this Shabtay ’383 method creates a new, higher-resolution array of pixels, and these new pixel values are determined based on data from both of the input images. The fusion method result is an output image that has a greater resolution than that of either of the input images, such that each pixel in the output image could only correspond to a portion of a pixel in either input.

48. Golan ’366 and Shabtay ’383 demonstrate that “fusion” has a plain and ordinary meaning within the art that is broader than what Apple has proposed. That prior art of record shows that “fusion” includes at least techniques which (1) involve combining image information, like

[2] Shabtay ’383 was disclosed to the Examiner during the prosecution in an April 13, 2015 Information Disclosure Statement.

combining the hue of one image's pixel with the intensity of another image's pixel to create a new combined pixel that would not be found in either source image, and (2) using image data from two images, including aggregate data representing an image region other than that of a single pixel, to create an entirely new image. Both, however, would be excluded by Apple's proposal to narrow "fusion" to necessarily require the ***combination of pixels***.

49. As another example, the '291 patent's own discussion of its invention reflects an understanding of "fusion" to be more than simply the combination or composite of ***pixels*** from two images. The patentees knew and used the words "fusion" and "pixel"—those and closely related words (e.g., "fused," "pixel," "pixelated") are used throughout the specification and the claims themselves. When discussing the concept of fusion, the patentees made clear that "fusion" referred to the combination of image ***information***. *See, e.g.*, '291 patent at ("In still mode, zoom is achieved "with fusion" (full or partial), by fusing W and T images, with the resulting fused image including always ***information*** from both W and T images.").

50. Next, Apple's proposed construction would also apparently exclude a preferred embodiment described in the patent specification. An embodiment shown in the patent discloses a "fusion" technique in which the output image does not include any pixels from one of the two input images – directly contrary to Apple's proposed construction. Figure 5 "shows an embodiment of a method disclosed herein for acquiring a zoom image in still mode." '291 patent, at 9:15-16. The embodiment is directed to an image fusion technique which uses image registration and resampling techniques to mitigate the effect of dissimilarities that two images of a given scene or object might have due to the spatial offset between the two cameras that captured the images. Figure 5 shows:

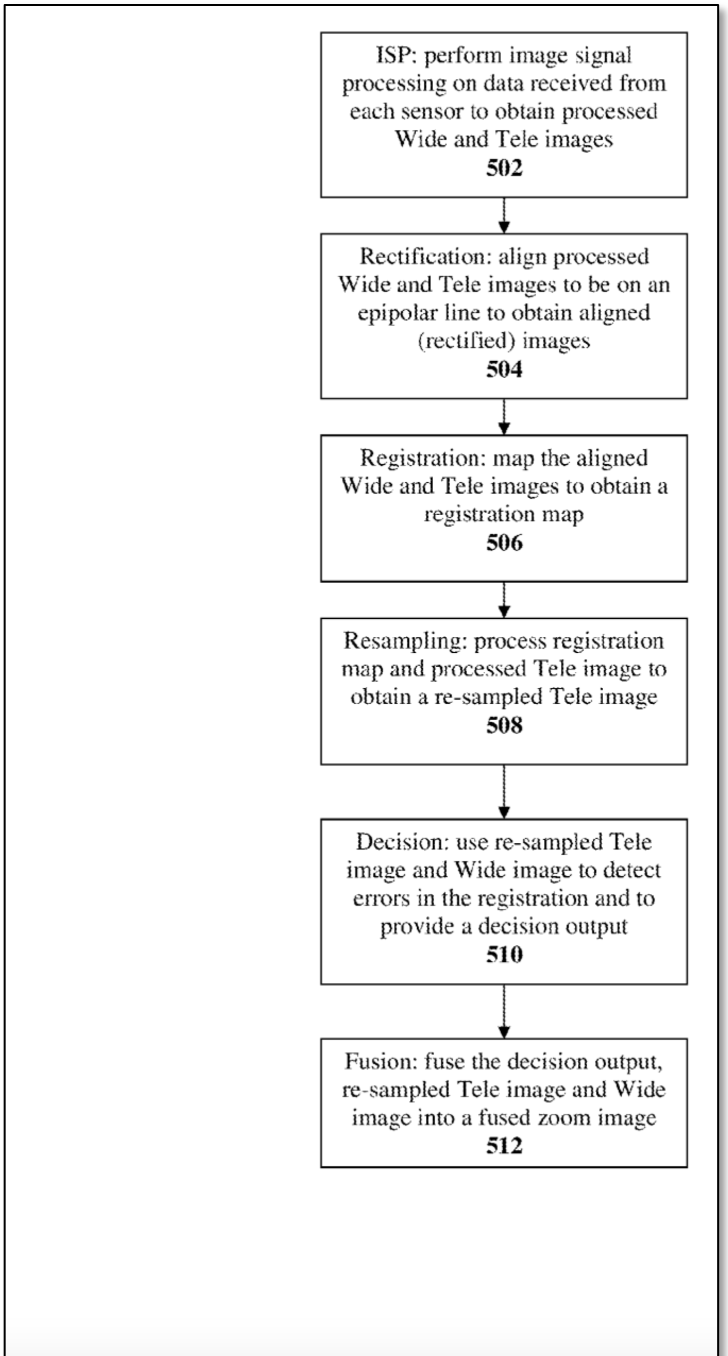

FIG. 5

The specification goes on, at 9:27-36:

the re-sampled Tele image and the Wide image are processed to detect errors in the registration and to provide a decision output. In more detail, in step 510, the re-sampled Tele image data is compared with the Wide image data and if the comparison detects significant dissimilarities, an error is indicated. ***In this case, the Wide pixel values are chosen to be used in the output image.*** **Then, in**

> **fusion step 512, the decision output, re-sampled Tele image and the Wide image are fused into a single zoom image.**

51. In the "output image" contemplated by Figure 5's Step 512 and the discussion above, the output image has only "pixels" from the image from the Wide imaging section, whereas the Tele image is resampled before data deriving from resulting resampled image is fused with pixels of the Wide image. The resulting fused output image has no "pixels" from the Tele image. Thus, Apple's proposal, which requires that the fused output image include pixels from ***both*** "Wide" and "Tele" images, would exclude the '291 patent's Figure 5 embodiment.

52. As this discussion also shows, where the patentees intended for an output image produced by image fusion to have the ***pixels*** of one input image or another, ***they said so***. That also means the patentees did not use the term "fusion" to mean ***only*** a technique which involved combining the pixels of inputs. Instead, the patentees used "fusion" according to its ordinary meaning representing this broader category of image processing methods consistent with the prior art of record and general knowledge of a POSITA.

53. Second, both of Apple's proposals improperly insert the word "composite" into the construction. The word "composite" does not appear to add clarity or impose any additional material limitation. The claims already require that image data from Tele and Wide cameras be "***combined*** … to provide a fused output image." '291 patent, cl. 1(c). Supplementing the claim meaning with a new word, "composite," produces no clarity on its face and, to the contrary, injects ambiguity into claim scope by suggesting there is a material difference between the meaning of the word "composite" and the claim's existing requirement that image data be "combined."

54. Third, both of Apple's proposed constructions for the disputed terms "fused output image" and "without fusion … output images" include the disputed claim terms "Wide" and "Tele." If they are accepted and applied to Apple's proposal for Term D, they would result in nonsensical

phrases. As one example, the claim phrase "Tele image(s)" would be transformed, under Apple's positions, into either (a) "telephoto images characterized by a TTL/EFL ratio less than 1" or (b) "images characterized by an effective focal length (EFL) longer than normal and field of view (FOV) narrower than normal." But it makes no sense to say an "image" is "characterized by a TTL/EFL ratio less than 1" or "characterized by an effective focal length." An image might be ***captured*** by a camera with a TTL and a lens that has a particular EFL or which produces a particular FOV, of course, but the camera's TTL, EFL and FOV are not characteristics of an "image."

55. Further, Apple's injection of "Wide" and "Tele" results in a redundancy: the claim language of the '291 patent already specifies that an "output image" is the result of combining "at least some of the Wide and Tele image data." To illustrate, claim 1(c) of the '291 patent recites:

> c) a camera controller operatively coupled to the Wide and Tele imaging sections, the camera controller configured to ***combine*** in still mode at least some of the ***Wide*** and ***Tele image data*** to ***provide a fused output image*** of the object or scene from a particular point of view and to provide without fusion continuous zoom video mode output images of the object or scene, each output image having a respective output resolution;

56. And Apple also contends "image data" should be limited to data that "represents pixels," Apple's proposals for Term D result in repetitive and unwieldly claim language. For example, claim 1(c) would be transformed like so:

> c) a camera controller operatively coupled to the Wide and Tele imaging sections, the camera controller configured to combine in still mode at least some of the *Wide* and *Tele* [*data that represents image pixels]* to *provide* [*a composite output image that includes pixels from the Wide and Tele images*] of the object or scene from a particular point of view and to provide [*output images that do not include a composite image that includes pixels from the Wide and Tele images*] of the object or scene, each output image having a respective output resolution;

57. Finally, I understand that Apple previously admitted, in IPR proceedings applying the same *Phillips* claim construction standard, that the proper construction of fusion involved combining

information from two images, not combining pixels from two images. That prior proposal from Apple is consistent with Corephotonics's current proposal and virtually matches the named inventors' own discussion of fusion (e.g., in the Shabtay '383). For those reasons and the others discussed above, it is my opinion that Corephotonics' proposal accurately captures the meaning of the terms according to their ordinary meaning and as used in the intrinsic record.

E. "fused output image of the object or scene from a particular point of view" (*'291 patent, claims 1, 12*)

Corephotonics' Proposed Construction	Apple's Proposed Construction
"output image of the object or scene from a particular point of view" means that "the object and scenes of the output image have the position and shape as would be seen from a defined point of view of one of the Wide or Tele lens" "a fused output image of an object or scene from a particular point of view" means "a composite / output image that if from the Wide POV combines Wide image data with image data from the overlap region of the Tele image, and if from the Tele POV, combines Tele image data with image data from the overlap region of the Wide image"	"a fused output image of an object or scene from a particular point of view" means an output image of an object or scene that is always a composite of both Wide and Tele image pixels, whether from the Wide or Tele point of view. "an output image of an object or scene that is always a composite of both Wide and Tele image pixels, whether from the Wide or Tele point of view" "output image of the object or scene from a particular point of view" – no separate construction is necessary. If the Court determines that construction is necessary, "output image of the object or scene from a particular point of view" means an output image of the object or scene from the Wide or Tele point of view.

58. The parties' dispute in Term E includes whether a "fused output image" is an output image "of an object or scene that is always a composite of both Wide and Tele image pixels." The core of the parties' dispute as to this portion of Term E is whether "fusion" (and "fused output image") is something which necessarily or ("always") requires a combination or composite of "pixels" from multiple other images. This issue is addressed in detail above in my discussion for Term D.

59. Second, the remainder of the parties' dispute for Term E concerns whether what claim language "particular point of view" should have on claim scope. Apple proposes no separate construction and provides no argument about what "particular point of view" or "point of view" mean.

60. Unlike Apple's proposed construction, Corephotonics' proposed construction is informed by the '291 patent's definition of point of view (POV). Following from the foregoing description of the '291 patent in § II.B, the relevant "point of view" of the camera is determined by position and shape of objects and scenes that the camera captures:

> In a dual-aperture camera image plane, as seen by each sub-camera (and respective image sensor), a given object will be shifted and have different perspective (shape). This is referred to as point-of-view (POV). **The system output image can have the shape and position of either sub-camera image or the shape or position of a combination thereof.** If the output image retains the Wide image shape then it has the Wide perspective POV. If it retains the Wide camera position then it has the Wide position POV. The same applies for Tele images position and perspective.

'291 pat., 4:60-5:2 (emphasis added). The specification also teaches:

> In order to reach optical zoom capabilities, a different magnification image of the same scene is captured (grabbed) by each camera sub-camera, resulting in FOV overlap between the two sub-cameras. Processing is applied on the two images to fuse and output one fused image in still mode. The fused image is processed according to a user zoom factor request. As part of the fusion procedure, up-sampling may be applied on one or both of the grabbed images to scale it to the image grabbed by the Tele sub-camera or to a scale defined by the user. The fusion or up-sampling may be applied to only some of the pixels of a sensor. Down-sampling can be performed as well if the output resolution is smaller than the sensor resolution.

61. The specification of the '291 patent goes on to teach methods for generating fused output images with a (single) particular, consistent POV from the information in the Wide and Tele camera images. *See id.*, 5:5-10, 9:15-36, Fig. 5. Corephotonics's proposal captures this particular context by providing clarification which Apple does not appear to dispute: that an output image with one camera's "point of view" is created using image data from the overlap region in the image

produced by the other camera. Apple also does not appear to dispute that for an image to have a particular "point of view" means that the "the object and scenes of the output image have the position and shape as would be seen from a defined point of view" of the lens of a specific imaging section.

F. "image data" (*'291 patent, claims 1, 2, 12*)

Corephotonics' Proposed Construction	Apple's Proposed Construction
plain and ordinary meaning, or, in the alternative if the Court determines a construction is necessary, "data output from an imaging section"	data that represents image pixels.

62. The parties dispute here centers on whether "image data" in the context of the claims must be data that "represents image pixels," or whether it may include data that does not "represent" specific pixels but instead reflects other image-related data such that reflecting the luminance or intensity of an image, both of which a POSITA would understand the plain and ordinary meaning of this term to include. It is my opinion that its proposal is incorrect in view of the relevant evidence, and this term should be accorded its full plain and ordinary meaning.

63. As an initial matter, Apple's proposal is defective because it is vague. It is unclear what Apple means for data to "represent" pixels. The term "represent" is inherently inexact and, when used in an ordinary English sentence, connotes a variable degree of separation between a subject and object. If Apple intends for its proposal to mean that only something which shows the RGB values of a given pixel in a matrix of pixels is "image data," then its proposal is wrong for the reasons already discussed above. It is also unclear, for example, whether "data which represents image pixels" is broad enough to encompass luminosity and intensity data, which are types of image data discussed below.

64. Further, the intrinsic record is clear that "image data" is not limited to simply data that "represents" pixels, and that this is a plain and ordinary meaning existing as matter of convention followed by person of skill in the art. For example, U.S. Patent App. Pub. 2011/0064327 to Dagher et al. ("Dagher") is cited and discussed in the '291 patent as an example of existing "[m]ulti-aperture imaging systems." *See* '291 patent, at 2:1-3. Dagher is directed to a system and method for "image data fusion" based on first and second sets of image data. *See* Dagher, at Abstract. Dagher at [0009] & [0011] shows that the phrase "image data" does not mean simply data representing individual RGB values in an array of pixels, but that it also refers to a given image's luminosity (based on an image's luminosity channel) and intensity information:

> In another aspect, the first collection of overlap image data may include a first collection of luminance data, and the selected one of the image data subsets may be a luminance channel (of luminance data) based on luminance as the characteristic of the second collection of overlap image data, and changing of the first collection of overlap image data may include combining the first and second collections of luminance data. Arranging of the second sub-camera may include supplying the second sub-camera as a grayscale camera for providing the luminance channel as being composed of grayscale scaled image data. …
>
> In an additional aspect, the second collection of overlap image data may include intensity information, and scaling the second collection of overlap image data may include changing at least some of the intensity information. In this case scaling the second collection of overlap image data includes applying a gain for causing the changing of the intensity information.

65. Moreover, it is commonly known in the art that an "image," even a "digital image," need not be a rectangular matrix of pixels or have any "pixels" at all in any sense of the term. In today's usage, many (or even most) digital images begin their existences as digital data in an uncompressed format, which is in most cases a standard array of colors assigning RGB values to cells in a mathematical matrix and which can be interpreted by software to display an image. The bitmap may be compressed with encoding with any available compression algorithm such as run-length encoding or a lossy compression algorithm just as JPEG. In such compressed formats, each

element of image data does not correspond directly with each image pixel. Images in this class are called "raster" images.

66. Furthermore, not all digital images are "raster" images. Many digital images do not rely on bitmaps and pixels at all but instead are rendered from a collection of mathematical statements that define lines and other geometric shapes on a Cartesian plane and, often, also contain instructions on which bounded areas on the Cartesian plane (those boundaries being defined by the geometric shapes) are filled in with which colors. This is the "vector" class of digital images, and at its basic level not unlike how a laser-light show draws images, old videogames like Tempest and Asteroids generated graphics, or how older EKG monitors would display a heartbeat. In modern form, they are the basis for the SVG scalable vector graphics commonly used in webpages, and clipart drawings are managed in slideshows in the latest versions of PowerPoint and Keynote presentation software applications. And because vector images do not have "pixel" data at all (and nor would a POSITA believe they do), Apple's proposal here improperly narrows the term "image data" by narrowing the term to exclude non-raster images such as vector images for which "pixels" do not exist.

G. "lens assembly" (*'712 patent, claims 1, 12, 13, 15, 16, 19*)

Corephotonics' Proposed Construction	Apple's Proposed Construction
Plain and ordinary meaning, or, in the alternative if the Court determines that a construction is necessary, "arrangement of optical lens elements"	a five lens element optical lens assembly. Alternatively, "lens assembly" means "a self-contained operational unit of five optical lens elements," or alternatively "a lens limited to five elements."

67. The parties' dispute over "lens assembly" centers around whether the term "lens assembly" should import limitations that are not part of the meaning of that term – specifically to be narrowly

defined to be a “lens assembly” with “five optical lenses.” The claim language and intrinsic evidence of the ’712 patent make clear it should not.

68. As an initial matter, the phrase “lens assembly” consists of two common English words each easily understood by a person of ordinary skill in the art and which, when combined together, form a phrase whose plain meaning is also easily understood and needs no further construction.

69. In fact, as its proposals reflect, Apple largely agrees that the term “lens assembly” needs no construction. Its preferred construction simply appends five additional words—“a five lens element optical”—to the phrase “lens assembly.” Similarly, its two alternative proposals also impose a five-element limitation on “lens assembly” and do not add anything else other than, in the case of Apple’s first alternative proposal, to specify that an “assembly” must be a “self-contained operational unit.”

70. However, the phrase “lens assembly” by itself does not connote or expressly require a specific number of lens elements, as would be apparent to any student in a first-year optics class or even a lay person perusing an optics textbook. In fact, the specification refers to lens assemblies with more or less elements. *See, e.g.,* ’712 patent, at 1:32-34 (four lens elements). Likewise, the applicant in the prosecution leading to the ’712 patent cited numerous patents and publications which refer to lens assemblies with varying numbers of lens elements, without even an implication that the drafted claims’ use of that term should be limited in the way Apple suggests. *See, e.g.*, U.S. Patent No. 5,946,142 (six-lens assembly cited in 1/8/2017 IDS); U.S. Patent App. Pub. 2007/0229987 (three-lens assembly cited in 1/8/2016 IDS).

71. To the extent claims of the ’712 patent do require a particular number of elements that requirement is separately claimed and not a part of the term “lens assembly.” For example, claim 1 requires a “lens assembly, comprising: a ***plurality*** of refractive lens elements.” The claim does

not require "five refractive elements" or a "lens assembly" which is "limited to five refractive lens elements." Claim 1 then subsequently requires that the claimed "lens assembly" comprise "a first lens element," "a second lens element," and "a third lens element," but does not claim, for example, a "fourth" or "fifth" lens element. Thus, claim 1's "lens assembly" must comprise at least three lens elements and, by implication, may be practiced with a lens assembly with three lens elements.

72. Notwithstanding claim 1, ***other*** claims of the '712 patent ***do*** specify fourth and/or fifth lens elements being a part of the "lens assembly." Claim 2, for example, depends from claim 1 and further requires that the "plurality of lens elements ***further comprises*** a fourth lens element." And claim 4, depending from claim 2, further adds a "fifth lens element" requirement to the claimed "plurality of lens elements." The structure and ordering of these claims is suggests that the drafter chose to claim, in the independent claims, a lens assembly with at least three lens elements, and to locate requirements for a "fourth" and "fifth" lens elsewhere, to the dependent claims. The drafter plainly did not intend the phrase "lens assembly" to take on a specific "five element" requirement as Apple proposes, nor would a POSITA understand it to include these additional requirements simply due to how the patent claims are arranged. If the Court deems it necessary to construe this term, only Corephotonics's proposal faithfully reflects the intrinsic record: "arrangement of optical lens elements."

73. Apple may point to broad goal-oriented statements in the specification to support its construction. For example, the specification disparages certain "four lens element" assemblies as being "no longer sufficient for good quality imaging," and says that there is a "need" for a "five lens element optical lens assembly that can provide a small TTL/EFL ratio and better image quality than existing lens assemblies." '712 patent, at 1:31-41. But the ***number*** of lenses in the claimed assembly is not a crucial aspect of the invention. Indeed, if the term "lens assembly" by

itself meant an assembly of five lens elements, then the specification's reference to a lens assembly with four elements would be nonsensical. The inventor, in the same breadth, criticizes other five-lens assemblies as inadequate (*id.* at 1:36-39), and nowhere emphasizes the superiority or inventiveness of having five lenses versus, say, six or seven lenses.

74. Apple may also point to embodiments in the specification which reflect lens assemblies with five lenses, such as Figures 2A and 3A. I understand that aspects of embodiments may not be imported into the claims absent a compelling justification to do so.

75. Finally, as for Apple's alternative proposal adding "a self-contained operational unit" as a requirement modifying "lens assembly," I am aware of no intrinsic or extrinsic evidence supporting such a construction. Further, I believe the descriptor "self-contained operational unit" is vague and subject to potentially competing interpretations, even to a POSITA.

I declare under penalty of perjury that the foregoing is true and correct.

Executed September 29, 2022, in Champaign, Illinois.

By: ______________________
John C. Hart

EXHIBIT A

Curriculum Vitæ

John C. Hart

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and
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Experience

Education

- **Ph.D.** Electrical Engineering and Computer Science Dept., University of Illinois at Chicago, 1991. Thesis title: ``Computer Display of Linear Fractal Surfaces." Advisor: Thomas A. DeFanti.
- **M.S.** EECS Dept., University of Illinois at Chicago, 1989. Thesis title: ``Image Space Algorithms for Visualizing Quaternion Julia Sets." Advisor: Thomas A. DeFanti.
- **B.S.** College of Liberal Arts and Science, Aurora University, 1987. Major: Computer Science.

Academic Positions

- **Director, Office of Professional Education**, University of Illinois at Urbana-Champaign, 2021-.
- **Director of Online Programs**, Dept. of Computer Science, 2018-2021.
- **Director**, Master of Computer Science in Data Science program, 2016-2017.
- **Executive Associate Dean.** Graduate College, University of Illinois, 2015-2021.
- **Associate Dean.** Graduate College, University of Illinois, 2014-2015.
- **Director for Graduate Studies.** Dept. of Computer Science. 2013.
- **Full Professor**. Dept. of Computer Science, University of Illinois, 2006-.
- **Associate Professor**. Dept. of Computer Science, University of Illinois, 2000-2006.
- **Associate Professor**. School of Electrical Engineering and Computer Science, Washington State University, 1998-2000.
- **Assistant Professor.** School of Electrical Engineering and Computer Science, Washington State University, 1992-1998.
- **Postdoctoral Research Associate.** Electronic Visualization Laboratory, University of Illinois at Chicago, and National Center for Supercomputing Applications, University of Illinois at Urbana-Champaign, 1991-1992.
- **Research Assistant.** Electronic Visualization Laboratory, Electrical Engineering and Computer Science Dept., University of Illinois at Chicago, 1988-1991.

- **Teaching Assistant.** Analog & digital circuit design courses, EECS Dept. University of Illinois at Chicago, 1987-1988.

Awards and Honors

- **The Excellence in Online & Distance Teaching Award**. University of Illinois at Urbana-Champaign, 2021.
- **Fellow.** Academic Leadership Program, Big Ten Academic Alliance, 2016-2017.
- **Outstanding Advisor.** College of Engineering, 2010 and 2015.
- **Winner.** 2004 Fantasy Graphics League.
- **Listed.** *International Who's Who of Professionals,* 1997.
- **Champion.** SIGGRAPH Bowl II, SIGGRAPH 94. Captain of the EVL Alumni Team.
- **NSF Research Initiation Award.** "Modeling, Rendering and Animation of Implicit Surfaces," to support the generalization of methods developed for the visualization of fractal models to the more common implicit surfaces used in CAGD and entertainment, 1993.
- **First Runner-Up.** Truevision Videographics Competition, SIGGRAPH 90.
- **Graduate Fellowship.** Graduate College, University of Illinois at Chicago, 1990-1991.

Industry Consulting

- **Intrinsic Medical Imaging LLC**, Bloomfield Hills, MI. Consultant, 2012-13. Mesh construction and simulation of coronary arterial blood flow.
- **Pratt & Whitney**, Hartford, CT. Consultant, 2011. Flux estimation in a lensed system.
- **Science Applications International Corp. (SAIC),** Champaign, IL. Consultant, 2008. Ray-NURBS intersection.
- **Adobe Systems, Inc.,** Seattle, WA. Visiting Researcher, 2007. Project: Rendering meshed objects as stylized vector art.
- **The Teaching Company,** Chantilly, VA. Consultant, 2003. Produced custom educational video elements on the platonic solids.
- **Evans & Sutherland Computer Corp.,** Salt Lake City, Utah. Consultant, 1999-2000. Project: Design of the Evans & Sutherland Multi-Texturing Language.
- **Blue Sky | VIFX, Inc.,** Culver City, California. Consultant, 1998. Project: development of a custom software plug-in for the Houdini procedural animation package to polygonize a feature film villain modeled as a complex implicit surface.
- **Evans & Sutherland Computer Corp.,** (group formerly known as Silicon Reality, Inc.) Federal Way, Washington. Consultant, 1997-8. Project: design of graphics hardware to support antialiased procedural solid texturing.
- **Kleiser-Walczak Construction Company (a visual effects production company).** Lennox, Massachussetts. Consultant, 1992-1993. Project: development of a new fractal-based video transition effect for an attraction at the Luxor Hotel, Las Vegas.
- **AT&T Pixel Machines.** AT&T Bell Laboratories, Holmdel, New Jersey. Summer Intern, 1990.
- **IBM T.J. Watson Research Center.** Hawthorne, New York. Summer Intern, 1989.

Expert Testimony

(Only includes disclosed engagements.)

- **Advanced Micro Devices (AMD)** v. RealTek, TCL. US International Trade Commission Case #337-TA-1318. Retained by Mintz, Levin, Cohn, Ferris, Glovsky and Popeo PC. Testified at Markman Hearing 9/6/22. Ongoing,
- **Stratos Audio**. IPR's and trials regarding Patents 8,200,203, 8,688,028 and 8,903,307. Retained by White & Case LLP. Dec. 2021-ongoing. Deposed 3/31/22, 7/8/22, 7/12/22 and 7/20/22.
- **Infernal Technologies** v. Sony Interactive Entertainment, US District Court, Eastern District of Texas Marshall Division, C.A. No. 2:19-cv-248-JRG. Retained by Beuther, Joe & Counselors. Authored expert reports on infringement (Aug. 2020) and validity (Sep. 2020). Testified in jury trial Oct. 2021.
- **Intellectual Pixels,** Inter Partes Review for Patent 8,667,093. Retained by Armond Wilson. Mar. 2021 – June 2022. Authored declaration. Deposed 18 June 2021.
- **CorePhotonics**, Inter Partes Reviews for Patents 10,225,479 and 10,230,898. Retained by Russ, August & Kabat. Jan. 2021 – ongoing. Authored declarations. Deposed 29 Apr. 2021 and 21 May 2021.
- **LG Electronics Inc.**, US District Court, Central District of California, Western Division. Case No. 2:19-cv-09474-JAK. Retained by Sidley Austin Jan. 2020. Authored Sep 2020 expert report on claim construction.
- **Align Technology, Inc.**, US District Court for the District of Delaware, C.A. No. 17-1647-LPS-CJB. Retained by Morrison Foerester Mar. 2019. Authored infringement report and reply report on validity. Deposed 19 June 2020. Settled Feb. 2022.
- **Adsync Technologies**, Middle District of Florida, Orlando Division, Case 6:18-cv-1176-Orl-40TBS. Retained by Akerman Jun. 2019. Declaration in defense of Amended Complaint from Adacel and in support of counter complaint from Adsync. Deposed 24 Jan 2020. Settled Jan. 2021.
- **ZiiLabs** (subsidiary of Creative Technology), Certain Graphics Processors and Products Containing the Same, US International Trade Commission Case #337-TA-1099. Retained by Pepper Hamilton Sep. 2017. Deposed 12 Nov. 2018.
- **Samsung.** - FotoNation Ltd. et al. v. Samsung Electronics. Co., Ltd., et al., No. 2:17-cv-00669 (E.D. Tex.). Retained by O'Melveny & Myers Oct. 2017.
- **Samsung**, Inter Partes Reviews for of patents filed by Image Processing Technologies LLC: 6,717,518, 6,959,293, 7,650,015, 8,805,001, 8,983,134 and 8,989,445. Retained by O'Melveny & Myers Oct. 2016. Deposed Dec. 2017.
- **ZiiLabs** (subsidiary of Creative Technology), Certain Graphics Processors, DDR Memory Controllers, and Products Containing the Same, US International Trade Commission Case #337-TA-1037, for Pepper Hamilton LLP, Sep. 2016 – July 2017. Testified to the International Trade Commission for Markman hearing.
- **Advanced Silicon Technology**, Certain Computing or Graphics Systems, Components Thereof, and Vehicles Containing Same, US International Trade Commission Case #337-TA-984, for Mintz, Levin, Cohn, Ferris, Glovsky and Popeo PC, Aug. 2015 – Aug. 2016. Testified to the International Trade Commission for Markman hearing and authored validity report. Written declarations submitted for IPR2016-00894, -00897 and 01060).
- **ZiiLabs** (subsidiary of Creative Technology), Eastern District of Texas, Marshall Division, Case 2:14-cv-00203, for Heim, Payne & Chorush LLP and Susman Godfrey LLP. Sep. 2014 – Dec. 2015. Prepared invalidity rebuttal report for four patents and damages report for nine patents, all on graphics hardware. Deposed over two sequential days on both reports.

- **Graphics Property Holdings** (formerly SGI), Certain Consumer Electronics with Display and Processing Capabilities, US International Trade Commission Case #337-TA-884, for Mintz, Levin, Cohn, Ferris, Glovsky and Popeo . Graphics hardware expert on floating point rasterization, Authored report on patent validity. Deposed Feb. 2014. Testified to the International Trade Commission Apr. 2014.
- **Microsoft XBox**, Illinois Northern District Court (Eastern Division) Case #08-C-393, for Sidley Austin LLP. Dec. 2009 – May 2010. Prepared non-infringement rebuttal report and invalidity report.
- **NVIDIA & AMD (ATI)**, California Northern District Court Case # 3:07-cv-00302, for Cooley Godward Kronish LLP. July 2008 – Sep. 2008. Provided expertise on graphics hardware and insight into the industry-wide process for the deployment of innovative features.
- **Broadcom**, California Southern District Court Case #06-CV-0660, for McAndrews, Held & Malloy, Ltd, Dec. 2006 – Mar. 2007.

Research Funding

From Industry

- **Caterpillar,** through the **Digital Manufacturing & Design Innovation Institute**. $410,000, Co-PI with Placid Ferreira and Shiv Kapoor.
- **Intel.** Intel Illinois Parallelism Center. $2,500,000, Co-PI, 2011-2012.
- **Intel.** Leveraging Larrabee’s Programmable Rasterization. $130,000, 2009-2011.
- **Intel/Microsoft.** Universal Parallel Computing Research Center. $18,000,000, Co-PI, 2008-2012.
- **NAVTEQ**. “Surface Classification and Reconstruction from LIDAR and images.” $60,000, 2008.
- **Thomas M. Siebel.** “MethMorph: Visual Simulation of Methamphetamine Addiction.” $35,000, Spring 2006.
- **NVidia Corp.** $15,000 annually though the UIUC CS Affiliates Program, 2004–, and $125,000 total to date in Ph.D. student fellowships ($25K directly to the student to support one year of Ph.D. research): Nate Carr: 2002 & 2003, Jesse Hall: 2003 & 2004, Jared Hoberock: 2005 & 2008.
- **Microsoft Research.** “Precomputed Radiance Transfer Compression.” $15,000, Sep. 2002.
- **Evans & Sutherland Computer Corp.** “Real Time Procedural Solid Texturing.” $83,246, June 1999 – May 2000.
- **Evans & Sutherland Computer Corp. and Washington Technology Center.** “APST: Computer Graphics Hardware for Antialiased Procedural Solid Texturing.” $77,089. Aug. 16, 1998 - Aug. 15, 1999.
- **Intel Natural Data Types Group. “**Procedural Modeling.” $43,000. Aug. 16, 1997 - Aug. 15, 1998.
- **Intel Natural Data Types Group.** “Recurrent Modeling -- Beyond Fractal Block Coding.” (Co-PI with P. Flynn.) $93,000. Apr. 1, 1995 - Mar. 31, 1997.

From Government Agencies

- **NSF**. #OAC-1550554 “SI2-SSI: Collaborative Research: ParaTreet: Parallel Software for Spatial Trees in Simulation & Analysis” (co-PI with Laxmikant Kale), $170,000, Sep. 2016 – Aug. 2018.
- **NSF**. #OCI-1216788 “Collaborative Research: Conceptualizing an Institute for Using Inter-Domain Abstractions to Support Inter-Disciplinary Applications” (co-PI with David Padua and Philippe Geubelle, and other collaborators at Purdue and UT-Austin), $135,000, Oct. 2012 – Sep. 2016.

- **NSF**. #EF-1115112 "Collaborative Research: Digitization TCN: InvertNet--An Integrative Platform for Research on Environmental Change, Species Discovery and Identification" (co-PI with Christopher Dietrich, Christopher Taylor, Nahil Sobh and Umberto Ravaioli), $2,809,463, July 2011-June 2015.
- **NSF**. #OCI-1047764 "SI2-SSE: Collaborative Research: Lagrangian Coherent Structures for Accurate Flow Structure Analysis" (co-PI with Shawn Shadden) $251,643, Sep. 2010 – Aug. 2013.
- **NSF**. #IIS-0534485 "Analysis and Visualization of Complex Graphs" (co-PI with Michael Garland) $300,000, Sep. 2006 – Aug. 2009.
- **UIUC Critical Research Initiative.** "A New Approach to Bone Replacement." (Co-PI with Russ Jamison, Michael Goldwasser, Ben Grosser, Matei Stroila and Amy Wagoner Johnson.) $100,000, Sep. 2005 – Aug. 2006.
- **NSF Small Grant for Exploratory Research.** "Application Directed Surface Parameterization." $97,868, Jan. 2005 – Dec. 2005.
- **NSF/DARPA CARGO (Computational and Algorithmic Representations of Geometric Objects) Award.** "Robust Lagrangian Surface Propagation with Topological Control." (Lead PI, with Michael Heath, Jim Jiao and John Sullivan), $400,000, May 2003 – May 2006.
- **NSF Information Technology Research.** #NSG-0219594 "Making 3D Visibility Practical." (Co-PI with Steve LaValle, Jeff Erickson, Fredo Durand) $499,923. Aug. 2002 – Aug. 2005.
- **CNRS (Centre National de la Recherche Scientifique).** Supplement to "Making 3D Visibility Practical" to support UIUC – INRIA collaboration, $7,000, 2003-5.
- **NSF Information Technology Research.** #ACI-0113968 "Multipass Programming for Personal High-Performance Computing." $489,671, Aug. 2001 – July 2006.
- **NSF Information Technology Research.** #ACI-0121288 "Procedural Representation and Visualization Enabling Personalized Computational Fluid Dynamics." (Co-PI with David Ebert, David Marcum, Kelly Gaither and Penny Rheingans) $3,989,773. Aug. 2001 – July 2006.
- **NSF.** #NSG-9732379 "Applications of Morse Theory and Catastrophe Theory to Computer Graphics." (Co-PI with R. Lewis.) $220,541. Aug. 16, 1997 – Aug. 15 2000.
- **NSF.** #CCR-9529809 "Recurrent Modeling." (Co-PI with P. Flynn.) $206,435. June 15, 1996 - May 31, 1999. Research Experience for Undergraduates Supplement: $5,000. Jan. 1, 1998 - May. 31, 1999.
- **NSF Research Initiation Award.** #CCR-9309210 "Modeling, Rendering and Animation of Implicit Surfaces." $97,925. July 1, 1993 - June 30, 1996. Research Experience for Undergraduates Supplement: $4,885. Jan. 1, 1995 - Dec. 31, 1995.

Education Projects

- **Nokia University Cooperation Funding.** "Teaching Mobile Augmented Reality on the Windows Phone Platform." $11,377.64. 2013.
- **UIUC College of Engineering Strategic Instructional Initiatives Program.** Improvement of key ME courses (Statics, Dynamics and Solid Mechanics), $450,000, with MechSE Profs. Tortorelli, Dullerud Keane and West, 2012-2014.
- **NSF Special Project.** #EIA-9911033 "The Story of Computer Graphics Documentary Project." $48,000. Sept. 15, 1999 – Aug. 31, 2000.

Equipment Grants and Donations

- **Nokia**. Two Velodyne LIDAR scanners, 2013.

- **NVidia.** K20 graphics card, 2012.
- **Intel.** Dell XPS 12, $1,000, 2012.
- **Intel.** Two Knights Ferry development workstations, $4,940, 2009.
- **NVidia**. Various graphics cards, 2002-4.
- **ATI**. One graphics card, 2002.
- **Tektronix Phaser 340 Color Printer.** Tektronix. $5,000. Oct. 1995.
- **High-Performance Networking and Computing Infrastructure for Imaging Research.** (Co-PI with T. Fischer, P. Flynn and R. Bamberger.) NSF Research Instrumentation and Infrastructure. CISE Instrumentation Program, Office of Cross-Disciplinary Activites. $100,000. March 1, 1994 - April 30, 1996. Awarded: Jan. 1995.
- **Silicon Graphics Inc. Workstation Upgrade.** $9,000. Apr. 1993.
- **XAOS Tools.** Software Donation. Pandemonium and n-title. $6,500. Feb. 1993.
- **Karen Guzak.** Art Donation. 12 Prints. $4,800. May 1995.

Publications

Most of the following publications are available online via
http://graphics.cs.illinois.edu/~jch/papers.

Reviewed Publications

1. A.I. Ellis, W. Hunt and J.C. Hart. Real-Time Analytic Antialiased Text for 3-D Environments. Proc. High-Performance Graphics, Computer Graphics Forum 38(8), 2019, pp. 23-32.
2. A.J. Christensen, V. Srinivasan, J.C. Hart and A. Marshall-Colon. Use of computational modeling combined with advanced visualization to develop strategies for the design of crop ideotypes to address food security. Nutrition Reviews 76(5), May 2018, pp. 332-347.
3. P-C Wang, A.I. Ellis, J.C. Hart, C-H Hsu. Optimizing next-generation cloud gaming platforms with planar map streaming and distributed rendering. Proc. NetGames (15th Annual Workshop on Network and Systems Support for Games), 2017.
4. A. Marshall-Colon, S.P. Long, D.K. Allen, G. Allen, D.A. Beard, B. Benes, S. von Caemmerer, A.J. Christensen, D.J. Cox, J.C. Hart, P.M. Hirst, K. Kannan, D.S. Katz, J.P. Lynch, A.J. Millar, B. Panneerselvam, N.D. Price, P. Prusinkiewicz, D. Raila, R.G. Shekar, S. Shrivastava, D. Shukla, V. Srinivasan, M. Stitt, M. Turk, E.O Voit, Y. Wang, X. Yin, X. Zhu. Crops in silico: Generating Virtual Crops Using an Integrative and Multi-scale Modeling Platform. Frontiers in Plant Science, May 2017.
5. M. Chen, J.C. Hart and S. Shadden. Hierarchical Watershed Ridges for Visualizing Lagrangian Coherent Structures. Reviewed, accepted and presented at TopoInVis: Topology-Based Methods in Visualization, 2015. Published in: Topological Methods in Data Analysis and Visualization IV, H. Carr, C. Garth, T. Weinkauf, Eds. Springer Mathematics and Visualization Series, 2017, pp. 237-252.
6. A.I. Ellis, Warren Hunt and J.C. Hart. “SVGPU: Real Time 3D Rendering to Vector Graphics Formats.” Proc. High Performance Graphics, 2016.
7. M. Chen, S. Shadden and J.C. Hart. “Fast Coherent Particle Advection through Time-Varying Unstructured Flow Datasets.” IEEE Transactions on Visualization and Computer Graphics 22(8), pp. 1959-1972, 2016.

8. J. Kratt, M. Spicker, A. Guayaquil, M. Fiser, S. Pirk, O. Deussen, J.C. Hart, B. Benes. Woodification: User-Controlled Cambial Growth Modeling. Proc. Eurographics, Computer Graphics Forum 23(2), May 2015, pp. 361-372.
9. V. Lu, J.C. Hart. Multicore Construction of k-d Trees for High Dimensional Point Data. Proc. Advances in Big Data Analytics, July 2014.
10. P.R. Khorrami, V.V. Le, J.C. Hart, T.S. Huang. A System for Monitoring the Engagement of Remote Online Students using Eye Gaze Estimation. Proc. IEEE ICME Workshop on Emerging Multimedia Systems and Applications, July 2014.
11. V. Lu, I. Endres, M. Stroila and J.C. Hart. Accelerating Arrays of Linear Classifiers Using Approximate Range Queries. Proc. Winter Conference on Applications of Computer Vision, Mar. 2014.
12. D. Mayerich, J.C. Hart, Volume Visualization of Serial Electron Microscopy Images Using Local Variance. Proc. BioVis (IEEE Symposium on Biological Data Visualization), pp. 9-16, Oct. 2012
13. C. Dietrich, J. Hart, D. Raila, U. Ravaioli, N. Sobh, O. Sobh, C. Taylor. InvertNet: a new paradigm for digital access to invertebrate collections. ZooKeys 209, July 2012, pp. 165-181.
14. Y. Jia, M. Garland, and J.C. Hart. Social Network Clustering and Visualization using Hierarchical Edge Bundles. Computer Graphics Forum 30(8), Dec. 2011, pp. 2314–2327.
15. Y. Jia, V. Lu, J. Hoberock, M.J. Garland, J.C. Hart. Edge v. Node Parallelism for Graph Centrality Metrics. GPU Computing Gems – Jade Edition, Oct. 2011, pp 15-28.
16. M. Kamali, F.N. Iandola, H. Fang, J.C. Hart. MethMorph: Simulating Facial Deformation due to Methamphetamine Usage. Proc. International Symposium on Visual Computing. Sep. 2011.
17. M. Kamali, J. Cho, M. Stroila, E. Shaffer, J.C. Hart. Robust Classification of Curvilinear and Surface-like Structures in 3D Point Cloud Data. Proc. International Symposium on Visual Computing. Sep. 2011.
18. M. Kamali, E. Ofek, F. Iandola, I. Omer, J.C. Hart Linear Clutter Removal from Urban Panoramas. Proc. International Symposium on Visual Computing. Sep. 2011.
19. K. Karsch, J.C. Hart. Snaxels on a Plane. Proc. Non-Photorealistic and Artistic Rendering, Aug. 2011.
20. J. Hoberock, J.C. Hart. Arbitrary Importance Functions for Metropolis Light Transport. Computer Graphics Forum 29(6), 2010, pp. 1993-2003.
21. S. Shi, M. Kamali, K. Nahrstedt, J.C. Hart, R. Campbell. High-Quality Zero-Delay Remote Rendering System for 3D Video. Proc. Multimedia, Oct. 2010.
22. B. Choi, R. Komuravelli, V. Lu, H. Sung, R.L. Bochino, S.V. Adve, J.C. Hart. Parallel SAH k-D Tree Construction. Proc. High Performance Graphics, June. 2010.
23. Y. Jia, X. Ni, E. Lorimer, M. Mullan, R. Whitaker, J.C. Hart. RBF Dipole Surface Evolution. Proc. Shape Modeling International, June 2010.
24. W.-W. Feng, B.-U. Kim, Y. Yu, L. Peng, J.C. Hart, Feature-Preserving Triangular Geometry Images for Level-of-Detail Representation of Static and Skinned Meshes, ACM Transactions on Graphics 29(2), March 2010, Article 11.
25. J. Hoberock, V. Lu, Y. Jia, J.C. Hart. Stream Compaction for Deferred Shading. Proc. High Performance Graphics, Aug. 2009.
26. J.C Hart. Assistive Technology for the Aesthetically Impaired. Proc. CHI Workshop on Computational Creativity Support, Apr. 2009.
27. J. Hoberock, S. Hornus, J.C. Hart. On Constructing and Visualizing the Topological Structure of the Visibility and Radiance of Architectural Models. Proc. TopoInVis: Topological Methods in Data Analysis and Visualization, Feb. 2009.
28. Y. Jia, J. Hoberock, M. Garland, J.C. Hart. On the Visualization of Social and other Scale-Free Networks. (Proc. Infovis), IEEE Transactions on Visualization and Computer Graphics 14(6), Nov. 2008, pp. 1285-1292.

29. A. Godiyal, J. Hoberock, M. Garland, J.C. Hart. Rapid Multipole Graph Drawing on the GPU. Proc. Graph Drawing, Sep. 2008.
30. E. Eisemann, H. Winnemoller, J.C. Hart, D. Salesin. Stylized Vector Art from 3D Models with Region Support. (Proc. Eurographics Rendering Symposium), Computer Graphics Forum 27(4), June 2008, pp. 1199-1207.
31. M. Stroila, E. Eisemann, J.C. Hart. Clip Art Rendering of Smooth Isosurfaces. IEEE Transactions on Visualization and Computer Graphics 14(1), Jan. 2008, pp. 71-81.
32. H. Fang, J.C. Hart. Detail Perserving Shape Deformation in Image Editing. Proc. SIGGRAPH, ACM Transactions on Graphics 26(3), Aug. 2007, #12.
33. T. Bergstrom, K. Karahalios, J.C. Hart. Isochords: Visualizing Structure in Music. Proc. Graphics Interface, May 2007.
34. H. Fang, J.C. Hart. RotoTexture: Automated Tools for Texturing Raw Video. IEEE Transactions on Visualization and Computer Graphics 12(6), Nov. 2006, pp. 1580-1589.
35. X. Jiao, A. Colombi, X. Ni, J.C. Hart. Anisotropic Mesh Adaptation for Evolving Triangulated Surfaces. Proc. Meshing Rountable, Sept. 2006, pp. 173-190.
36. S. Dong, P.-T. Bremer, M. Garland, V. Pascucci, J.C. Hart. Spectral Surface Quadrangulation. Proc. SIGGRAPH, ACM Transactions on Graphics 25(3), July 2006, pp. 1057-1066.
37. N.A. Carr, J. Hoberock, K. Crane, J.C. Hart. Rectangular Multi-Chart Geometry Images. Proc. Sym. on Geom. Proc., July 2006, pp. 181-190.
38. N.A. Carr, J. Hoberock, K. Crane, J.C. Hart. Fast GPU Ray Tracing of Dynamic Meshes using Geometry Images. Prof. Graphics Interface, May 2006, pp. 203-209.
39. P.-T. Bremer, J.C. Hart. A Sampling Theorem for MLS Surfaces. Proc. Point Based Graphics, June 2005.
40. J.O. Talton, N.A. Carr, J.C. Hart. Voronoi Rasterization of Sparse Point Sets. Proc. Point Based Graphics, June 2005.
41. W. Su, J.C. Hart, A Programmable Particle System Framework for Shape Modeling, Proc. Shape Modeling International, June 2005.
42. S. Zelinka, H. Fang, M. Garland, J.C. Hart. Interactive Material Replacement in Photographs. Proc. Graphics Interface, May 2005.
43. S. Hornus, J. Hoberock, S. Lefebvre and J.C. Hart. ZP+: Correct Z-pass Stencil Shadows. Proc. ACM Symposium on Interactive 3-D Graphics and Games, Apr. 2005. **(Highest ranked paper according to review score.)**
44. H. Fang, J.C. Hart, "Textureshop: Texture Synthesis as a Photograph Editing Tool," ACM Transactions on Graphics 23(3) (also in Proc. SIGGRAPH 2004), Aug. 2004, pp. 354-359.
45. X. Ni, M. Garland, J.C. Hart, "Fair Morse Functions for Extracting the Topological Structure of a Surface Mesh," ACM Transactions on Graphics 23(3) (also in Proc. SIGGRAPH 2004), Aug. 2004, pp. 613-622. **(Second highest ranked paper according to tertiary review score.)**
46. N. Carr, J.C. Hart, "Painting Detail," ACM Transactions on Graphics 23(3) (also in Proc. SIGGRAPH 2004), Aug. 2004, pp. 845-852.
47. N. Carr, J.C. Hart, "Dynamic Clustering of Meshed Surfaces," Proc. Symposium on Geometry Processing, July 2004.
48. O.S. Lawlor, J.C. Hart, "Bounding Recursive Procedural Models using Convex Optimization," Proceedings of Pacific Graphics 2003, October 2003, pp. 283-292.
49. P-P. Sloan, J. Hall, J. Hart, J. Snyder. Clustered Principal Components for Precomputed Radiance Transfer. (Proc. SIGGRAPH 2003) ACM Transactions on Graphics 22(3), July 2003.
50. N.A. Carr, J.D. Hall and J.C. Hart, GPU Algorithms for Radiosity and Subsurface Scattering, Proc. Graphics Hardware, July 2003.

51. John C. Hart, Jeyprakash Michaelraj, Brent Baker. Structural Simulation of Tree Growth. The Visual Computer 19(2-3), May 2003, pp. 151-163.
52. P. Sherman, J.C. Hart. Direct Manipulation of Recurrent Models. Computers & Graphics 27(1), Feb. 2003, pp. 143-151.
53. A. Sheffer, J.C. Hart. Seamster: Inconspicuous Low-Distortion Texture Seam Layout. Proc. Visualization 2002, Oct. 2002.
54. N.A. Carr, J.D. Hall and J.C. Hart. The Ray Engine. Proc. Graphics Hardware 2002, Sep. 2002.
55. H. Fang, J. Hart. Randomly Accessible Procedural Animation of Physically Approximate Turbulent Motion. Proc. Computer Animation 2002, June 2002.
56. J. Hart, E. Bachta, W. Jarosz, T. Fleury. Using Particles to Sample and Control More Complex Implicit Surfaces. Proc. Shape Modeling International 2002, May 2002, pp. 129-136.
57. N. Carr, J. Hart. Meshed Atlases for Real-Time Procedural Solid Texturing. ACM Transactions on Graphics 21(2), Apr. 2002.
58. J.C. Hart. Perlin Noise Pixel Shaders. *Proc. Graphics Hardware 2001*, Aug. 2001.
59. W. Cochran, R. Lewis, J. Hart. The Normal of a Fractal Surface. *The Visual Computer 17*(4), 2001, pp. 209-218.
60. J.C. Hart. Using the CW-Complex to Represent the Topological Structure of Implicit Surfaces and Solids. *Proc. Implicit Surfaces '99*, Sept. 1999, pp. 107-112.
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64. W.O. Cochran, J.C. Hart, P.J. Flynn. On Approximating Rough Curves with Fractal Functions. *Proc. Graphics Interface '98,* June 1998, pp. 65-72.
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66. B. Stander, J.C. Hart. Guaranteeing the Topology of an Implicit Surface Polygonization. *Computer Graphics Annual Conference Series* (Proc. SIGGRAPH 97) Aug., 1997, pp. 279-286.
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68. B. Burch, J.C. Hart. Linear Fractal Shape Interpolation. *Proc. Graphics Interface '97.* May, 1997, pp. 155-162.
69. J.C. Hart, P.J. Flynn, W.O. Cochran. Similarity Hashing: A model-based vision solution to the inverse problem of recurrent iterated function systems. *Fractals 5*, Apr. 1997, pp. 39-50.
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79. J.C. Hart. Distance to an Ellipsoid. Chapter in: Graphics Gems IV, P. Heckbert, Ed., Academic Press, 1994, pp. 113-119.

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88. J.C. Hart, D.J. Sandin, L.H. Kauffman. Ray tracing deterministic 3-D fractals. *Computer Graphics 23*(3) (Proc. SIGGRAPH 89) Aug. 1989, pp. 289-296.

Books, Invited Book Chapters and Edited Course Notes

89. J. Torrellas, S.V. Adve, V.S. Adve, D. Dig, M.N. Do, M.J. Garzaran, J.C. Hart, T.S. Huang, W.W. Hwu, S.T. King, D. Marinov, K. Nahrstedt, D.A. Padua, M. Parthasarathy, S.J. Patel, M. Snir. “Making Parallel Programming Easy: Research Contributions from Illinois,” Sep. 2013.

90. M. Olano, W. Heidrich, J. Hart and M. McCool, Real Time Shading, AK Peters, July 2002.

91. J.C. Hart, "Procedural Geometry," Chapter in Modeling and Texturing, a Procedural Approach, 3rd Edition, D. Ebert, Editor, Morgan Kauffman, November 2002.

92. J.C. Hart, "Real-Time Procedural Solid Texturing," Chapter in Modeling and Texturing, a Procedural Approach, 3rd Edition, D. Ebert, Editor, Morgan Kauffman, November 2002.

93. D. Ebert and J. Hart, Editors, “Procedural Implicit Techniques for Modeling and Texturing," ACM SIGGRAPH 1998 Course Notes, July 1998.

94. D. Ebert and J. Hart, Editors, “New Frontiers in Modeling and Texturing,” ACM SIGGRAPH 1997 Course Notes, August 1997.

95. J. Hart and D. Saupe, Editors, “Fractal Models for Image Synthesis, Compression and Analysis,” ACM SIGGRAPH 1996 Course Notes, August 1996.
96. J. Hart, Editor, “New Directions for Fractal Modeling in Computer Graphics,” ACM SIGGRAPH 1994 Course Notes, July, 1994.
97. J. Hart and K. Musgrave, Editors, “Fractal Modeling in 3-D Computer Graphics and Imaging,” ACM SIGGRAPH 1991 Course Notes, July 1991.

Patents

98. H. Fang and J.C. Hart, Methods and Systems for Image Modification. #7,365,744. Filed: 26 July 2004, Granted: 29 April 2008.
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Invited Papers, Articles, Tech Reports and Other Publications

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101. S. Dong, P.-T. Bremer, M. Garland, V. Pascucci and J.C. Hart. Quadrangulating a Mesh using Laplacian Eigenvectors. Tech Rep. UIUCDCS-R-2005-2583, June 2005.
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103. J.D. Hall and J.C. Hart. GPU Acceleration of Iterative Clustering. Poster (with accompanying manuscript) for SIGGRAPH 2004 and GP2: The ACM Workshop on General Purpose Computing on Graphics Processors, Aug. 2004.
104. M. Mullan, R. Whitaker and J.C. Hart. Procedural Level Sets. Manuscript presented at NSF/DARPA CARGO Annual Meeting, May 2004.
105. J.D. Hall, N.A. Carr and J.C. Hart. Cache and Bandwidth Aware Matrix Multiplication on the GPU. Tech. Report UIUCDCS-R-2003-2328, May 2003.
106. M. Kameya, and J.C. Hart. Bresenham noise. SIGGRAPH 2000 Conference Abstracts and Applications, July 2000.
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108. A. Aceves, K. Hammil and J.C. Hart. Proposal and Partially Implemented: The Studio: A Large High Resolution Immersive Projection System for Research and Education. Proc. Western Computer Graphics Symposium. Mar. 1999.
109. M. Kameya and J.C. Hart. Bit Width Necessary for Solid Texturing Hardware. Proc. Western Computer Graphics Symposium. Mar. 1999.
110. N. Carr and J.C. Hart. APST Antialiased Procedural Texturing Interface for OpenGL. Proc. Western Computer Graphics Symposium. Mar. 1999.
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112. J.C. Hart. Computational Topology for Shape Modeling. Invited Talk and Paper. Proc. Shape Modeling International '99, Univ. Aizu, Japan, Mar. 1999, pp. 36-45.

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114. I.M. Danciu, J.C. Hart. Fractal Color Image Compression in the L*a*b* Uniform Color Space. Poster. Abstract in: Proc. of Data Compression Conference '97. IEEE Computer Society Press, Apr. 1997, p. 434.
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124. J.C. Hart. Parallel algorithms for visualization of multidimensional fractal objects (extended abstract.) Electronic Imaging East '90. Nov. 1990, pp. 459-462.
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Film and Animation Credits

128. Executive Producer (with C. Machover). “The Story of Computer Graphics.” A SIGGRAPH Production of a feature-length documentary on the human struggle to bring computer graphics from the inspired revelation that computers can be used to draw pictures to the present, where low-cost graphics and the Internet combine to provide virtual environments for people to communicate. Premiered at a special event in the Shrine Auditorium, LA, as part of the SIGGRAPH 99 Computer Animation Festival.
129. Contributor. “Air on the Dirac Strings.” Produced by L.H. Kauffman, G.K. Francis, D.J. Sandin. SIGGRAPH '93 Electronic Theater. SIGGRAPH Video Review 93, Aug. 1993.
130. Producer. “SIGGRAPH 93 Technical Session Sampler.” SIGGRAPH '93 Electronic Theater. Video compilation, narrated by J. Blinn. SIGGRAPH Video Review 91, Aug. 1993
131. Producer. “Highlights from the SIGGRAPH '92 Technical Session.” SIGGRAPH '92 Electronic Theater. Video compilation, narrated by J. Blinn.

132. Producer/Director/Animator. "Fun with Octrees: Graph Topologies on the Recurrent Cube." SIGGRAPH '92 Animation Screening Room. SIGGRAPH Video Review 87, Aug. 1992. Appears in: ``The Fractal Universe: Animation," Media Magic, 1993.
133. Producer/Director/Animator. "unNatural Phenomena." SIGGRAPH '91 Electronic Theater. SIGGRAPH Video Review 71, Aug. 1991. Appears in: ``The Fractal Universe: Animation," Media Magic, 1993. Excerpts appear in: ``Beyond The Minds Eye," Mirimar, and ``Prime Time Live," ABC.
134. Producer/Director/Animator (with S. Das.). "Sierpinski Blows His Gasket." SIGGRAPH '90 Animation Screening Room. SIGGRAPH Video Review 61, 1990. First Runner-Up, Truevision Videographics Competition, 1990. Appears in: ``The Fractal Universe: Animation," Media Magic, 1993.
135. Producer/Director/Animator. "Dynamics in the Quaternions." SIGGRAPH Video Review 42, 1989. Appears in: ``The Fractal Universe: Animation," Media Magic, 1993.

Educational Activities

Postdoctoral Associates

- Moussa Mansour, 2015-6. Visiting from Univ. Sao Paolo.
- Matei Stroila, 2005-6. Research Scientist, Navteq, Nokia, Here.
- Peer-Timo Bremer, 2004-6. Research Scientist, Lawrence Livermore National Labs.
- Nate Carr, 2004-5. Senior Research Scientist, Adobe.

Ph.D. Students

- Apollo Ellis. Apple Internship 2016.
- Mingcheng Chen (2016). Currently at Google.
- Victor Lu (2013). Currently at Nokia.
- Mahsa Kameya (2012). Currently at Microsoft. MSR Internship 2010.
- Yuntao Jia (2010). Currently at Facebook.
- Jared Hoberock (2008). Research Scientist, Nvidia. NVidia Fellowship 2005,2007. NVidia Internship 2005.
- Xinli Ni (2007). Currently at Google, Microsoft Internship 2005.
- Hui Fang (2006). Currently at Google. Adobe Internship 2005.
- Nate Carr (2004). Senior Research Scientist, Adobe. NVidia Fellowship 2002 and 2003. Intel Internship 1999. NVidia Internship 2002.
- Wayne Cochran (1998). Assistant Professor, School of Engineering and Computer Science, Washington State University, Vancouver.
- Bart Stander (1997), Full Professor, Computer and Information Technology, Dixie State College of Utah.

M.S. Students

- 2017: Yiwen Xu.
- 2015: Jared Saul.

- 2013: JohnMark Lau.
- 2011: Rajesh Bhasin.
- 2009: Apeksha Godiyal. Microsoft Visio.
- 2005: Jerry Talton (Ph.D. Stanford, 2012), Tony Kaap (Alias), Matei Stroila (NAVTEQ).
- 2004: Jesse Hall (NVidia, Microsoft Research Internship 2002. NVidia Fellowship 2003 and 2004), Patrick Lacz (RadTIME), Wen Su (NVidia).
- 2002: Hui Fang (continued), Ed Bachta **(**visualization programmer at IUPUI)
- 2000: Nate Carr (continued), Jay Kim.
- 1999: Chanikarn Kulratanayan.
- 1998: Jeyprakash Michaelraj (Alias).
- 1997: Paul Sherman (Periphery Consulting).
- 1996: Ioana Danciu. (Adobe), Brandon Burch (WSU Instructor), Yingjun Yu (Nokia), Wenbiao Jiang (CFD Research), Kurt Albrecht.
- 1994: Anand Ramagapalrao (Microsoft), Wayne Cochran (continued).
- 1992: Yongqi Yang (Adobe).

Courses Taught

UIUC Courses

- CS 498 Data Visualization (via the Coursera platform for the MCS-DS program)
- ENG 198 Grand Challenges (Fall 2012)
- CS 418 Interactive Graphics
- CS 419 Production Graphics
- CS 519 Scientific Visualization
- CS 497 JCH Advanced Shape Modeling (Fall 2000)
- CS 498 Procedural Modeling and Shading in Computer Graphics (Fall 2002)
- CS 498 Particle System Programming (Spring 2004, voluntary addition to course load)
- CS 498 Shape Modeling (Fall 2004)
- CS 598 JCH Surface Reconstruction (2008)
- CS 491 EH Computational Topology Seminar (co-organized with J. Erickson)
- CS 491 GHY Graphics Seminar (co-organized with M. Garland, Y. Yu)

WSU Courses

- CptS 330 Numerical Computing
- CptS 442 Computer Graphics
- CptS 443 Computer-Human Interaction

- CptS 548 Advanced Computer Graphics

Coursera Courses

- Data Visualization, July-Aug. 2015. Enrollment: 88,399 from 198 different countries, including 1,197 with signature track credit toward the Data Mining certificate.

SIGGRAPH Reviewed One-Day Courses

- 2005: "Modern Techniques for Implicit Modeling" (Terry Yoo, James O'Brien), and
  "GPU Shading and Rendering" (Marc Olano)
- 2004: "Real Time Shading" (Marc Olano)
- 2003: "Beyond Blobs: Recent Advances in Implicit Surfaces" (Terry Yoo, Greg Turk) and
  "Real Time Shading" (Marc Olano)
- 2002: "Beyond Blobs: Recent Advances in Implicit Surfaces" (Terry Yoo and Greg Turk, org.) and
  "Real Time Shading" (Marc Olano).
- 2001: "Real Time Shading" (Marc Olano)
- 2000: "Approaches for Procedural Shading on Graphics Hardware" (Marc Olano)
- 1998: "Procedural Implicit Techniques for Modeling and Texturing" (Co-organizer with D. Ebert)
- 1997: "New Frontiers in Modeling and Texturing" (Co-organizer with D. Ebert.)
- 1996: "Fractal Models for Image Synthesis, Compression and Analysis" (Co-organizer with D. Saupe),
  "Procedural Modeling, Texturing, and Animation Techniques" (D. Ebert) and
  "Implicit Surfaces for Geometric Modelling and Computer Graphics (Jai Menon and Brian Wyvill)
- 1995: "Procedural Modeling, Texturing, and Animation Techniques" (D. Ebert).
- 1994: "New Directions for Fractal Modeling in Computer Graphics" (Course organizer).
- 1993: "Design, Visualization and Animation of Implicit Surfaces" (J. Bloomenthal, B. Wyvill).
- 1992: "Fractals: from Folk Art to Hyperreality" (P. Prusinkiewicz).
- 1991: "Fractal Modeling in 3-D Computer Graphics and Imaging" (Co-organizer with K. Musgrave).

Other

- Adler Planerarium, Scientific Visualization by Supercomputer. Chicago, Sept.-Nov. 1988.

Invited Colloquia and Presentations

Note: colloquia presented for the purpose of interviewing have been omitted.

- **Symposium on the Future of Data Analytics of the American & Canadian Societies of Animal Science**, invited talk on "Data Visualization," July 2018.
- **Workshop High Throughput Phenotyping and Data Analytics**, invited talk on "Data Visualization," Univ. Maryland, Nov. 2017.
- **31st Discovery Conference on Big Data Dairy Management**, invited talk on "Data Visualization," Nov. 2016.

- **University of Lorraine,** June 2014.
- **University of Notre Dame,** Center for Research Computing, "High Performance Computer Vision, An Oxymoron?," May 2012.
- **Graphics Interface Conference,** Keynote: Assistive Technology for the Aesthetically Impaired," May 2011.
- **University of Iowa Computing Conference,** organized and invited by U. Iowa students, "Assistive Technology for the Aesthetically Impaired," Feb. 2010.
- **AMS MathViz09**, U. Illinois, "It's Nice to See This Stuff Actually Used for Something," Mar. 2009. Host: George Francis.
- **INRIA**, Grenoble, France, "Assistive Technology for the Aesthetically Impaired," Sep. 2009. Host: Elmar Eisemann.
- **Texas A&M University.** Distinguished Lecture: "Assistive Technology for the Aesthetically Impaired," Feb. 2008. Host: Scott Schaeffer.
- **NAVTEQ.** "Industry Collaborations," Nov. 2007, Chicago, IL. Host: Matei Stroila.
- **Adobe-MIT Research Retreat.** "Textureshop Redux," Oct. 2007, Cambridge, MA. Host: David Salesin and Fredo Durand.
- **University of Konstanz Summerschool**. "Computational Topology of Implicit Surfaces" and "Computational Topology of Meshes," Sep. 2006, Gaschurn, Austria. Host: Dietmar Saupe.
- **Wolfram Research.** "Mathematical Visualization," May 2006, Champaign, IL. Host: Roger Germundsson.
- **Carnegie-Mellon University.** "Surface Constrained Particle Systems" and "Global Illumination on the GPU," Feb. 2005. Host: Doug James.
- **Imagina.** "Global Illumination on the GPU," Monaco, Feb. 2005.
- **3D Festival.** "Global Illumination on the GPU," Copenhagen, Denmark, May 2004.
- **INRIA**, Grenoble, France, "Global Illumination on the GPU," Mar. 2004, Host: Samuel Hornus.
- **University of Utah.** "Global Illumination on the GPU," Oct. 2003, Host: Chuck Hansen.
- **NVidia U.** Keynote speaker. July 2003, Host: Herbert Hu.
- **Army High Performance Computing Research Center (AHPCRC) Workshop on Graphics Modeling, Simulation and Visualization**. "Harnessing the Supercomputer in your PC's Graphics Card," June 2003. Host: Boquan Chen.
- **University of Illinois at Chicago (Math Dept.).** "Computational Topology for Computer Graphics." Apr. 2002. Host: Anatoly Libgober.
- **Colorado Springs SIGGRAPH Chapter**. "The Quest for Real-Time Procedural Solid Texturing." Mar. 2001. Host: Dino Schweitzer.
- **Northwestern University**. "The Quest for Real-Time Procedural Solid Texturing." Oct. 2000. Host: Benjamin Watson.
- **Shape Modeling International.** Invited Speaker, Aizu, Japan, March 1999.
- **Universität Freiburg.** "Recurrent Modeling." Sep. 1997. Host: Dietmar Saupe.
- **University of Utah.** "The Topology of Implicit Surfaces." Feb. 1997. Host: Chuck Hansen.
- **University of Illinois at Chicago (EECS Dept.).** "The Topology of Implicit Surfaces." Feb. 1997. Host: Tom DeFanti.
- **Interval Research.** "Recurrent Modeling." July 1996. Host: Sally Rosenthal.

- **University of Washington.** “Recurrent Modeling.” Dept. of Computer Science and Engineering. Jan. 1996. Host: Linda Shapiro.
- **Boeing Information & Support Services.** “Why Fractal Image Compression Isn't Fractal.” Computer Graphics & Multimedia Group. Jan. 1996. Host: David Kerlick.
- **University of Idaho.** “Why Fractal Image Compression Isn't Fractal.” Computer Science Dept. Nov. 1995. Host: Deborah Frincke.
- **NATO Advanced Study Institute** on Fractal Image Compression and Image Analysis. “Similarity Hashing: A model-based vision solution to the inverse problem of recurrent iterated function systems.” July 1995.
- **Simon Fraser University.** “Recurrent Modeling.” School of Computing Science. July 1995. Host: F. David Fracchia.
- **University of Calgary.** “Procedural Geometric Instancing.” Dept. of Computer Science. Jan. 1994. Host: Przemyslaw Prusinkiewicz.
- **Purdue University.** “Linear Fractals in Computer Graphics.” Computer Science Dept. June 1992. Host: Chandrajit Bajaj.

Professional Activities

Editorships and Papers Chairships

- Area Editor (Visual Computing) and Editorial Board Member, ACM Books 2014-.
- Papers Co-Chair (with Scott Schaefer), Shape Modeling International, 2012.
- Editor-in-Chief, ACM Transactions on Graphics, 2002-2008. Past EiC, 2008-2011.
- Associate Editor, ACM Transactions on Graphics, 2000-2002, 2011-.
- Guest Editor, Communications of the ACM 35(6) June 1992.
- Guest Editor, SIGGRAPH Video Review 96, ``Video Supplement to the Conference Proceedings," Aug. 1993.
- Guest Editor (with E.E. Catmull), SIGGRAPH Video Review 86, ``Video Supplement to the Conference Proceedings," July 1992.

Professional Organization Leadership

- SIGGRAPH Small Conferences Committee, 2010-
- Chair, SIGGRAPH Service Award, 2005-8.
- ACM SIGGRAPH Advisory Board, 2005.
- Director for Communications, SIGGRAPH Executive Committee, 1996-9.
- Director at Large, SIGGRAPH Executive Committee, 1994-6.

External Research Center Review Panels

- King Abdullah University of Science and Technology, Mar. 2012.

- Science Foundation Ireland, Oct. 2006.
- INRIA Systemes Cognitifs D, May 2006.

Conferences Chaired

- Co-Chair (with A. Marshall-Colon, S.P. Long and E.H. DeLucia), Plants-in-Silico, NCSA, UIUC, 2016.
- Co-Chair (with S. Gao, J. Jorge, K. Polthier and W. Wang), Shape Modeling International, Hong Kong, Oct. 2014.
- Co-Chair (with Marie-Paule Cani), Shape Modeling International, MIT, June 2005.
- Co-Chair (with K. van Overveld), Implicit Surfaces, Eindhoven, Netherlands, 1996.
- Chair. Western Computer Graphics Symposium, Panorama, BC, 1996.

Program Committees

- SIGGRAPH Papers Committee: 2001, 2006, 2007, 2010
- SIGGRAPH Asia Papers Committee, 2008.
- SIGGRAPH Sketches Jury: 1998, 1999.
- Symposium on Geometry Processing, all since 2006.
- Interactive 3D Graphics and Games, all since 2005.
- Pacific Graphics, all since 2002.
- Shape Modeling International, all since 1997.
- Implicit Surfaces (all).
- Eurographics 2004.
- Graphics Hardware, all since 2004.
- Web3D 2003.
- IEEE Virtual Reality 2000, 2001, 2002.
- Virtual Reality Annual International Symposium 1998.
- Visualization and Mathematics 1997.
- Supercomputing 1991-3, 1995.

Memberships

- Association for Computing Machinery
- ACM Special Interest Group on Computer Graphics and Interactive Techniques (SIGGRAPH)
- IEEE Computer Society

University of Illinois Committees

University of Illinois System

- Steering Committee, Start MyResearch Portal for university system-wide research management software, 2014-2016.
- University Technology Management Team, 2012-2013.

Urbana-Champaign Campus

- Ex-Officio (Graduate College Representative), Senate Educational Policy Committee, 2014-.
- Chair, Senate Subcommittee on IT, 2013-6, Member, 2008-2010.
- University Senate Executive Committee, 2013-6.
- IT Governance Executive Committee, 2012-5.
- Chair, IT Governance Research Subcommittee, 2012-5.
- Chair, Stewarding Excellence IT Project Team, 2010.
- Human Factors Transition Committee, 2008-9.
- Senate, 2007-14,

College of Engineering

- Chair, Promotion & Tenure Committee, 2013, Member 2012-2013.
- Vice-Chair, Executive Committee, 2013. Secretary, 2012-2013. Member, 2011-2013.
- Chair, Engineering IT Steering Committee, 2010-11.

Dept. of Computer Science

- Area Chair, Graphics and Human-Computer Interaction, 2004-2011.
- Department Head Search Committee, 2007-9.
- Advisory Committee (peer elected), 2005-2006.
- Industry Relations Committee, 2005-2007.
- Technology, Facilities and Services Committee (CS), 2005-2012.
- Engineering Open House CS Representative (CS), 2001-2006.
- Recruiting Committee, 2004, 2005.
- Curriculum Committee, 2002-3.
- Chair, Distinguished Lecture Series 2001-2002, Member 2000-2002.
- Computer Systems (CS), 2000-2001.
- Fellowships, Assistantships and Admissions, 2000-2001.

WSU

- School of EECS Computer Science Area Chair, 1998-2000.
- School of EECS Computer Science Accreditation Coordinator, 1999-2000.
- School of EECS Curriculum Committee 1998- (Chair, 1999-2000).
- School of EECS Graduate Studies Committee 1993-8.
- School of EECS Laboratory Committee 1994-6.
- WSU Center for Visualization, Analysis and Design in the Molecular Sciences (VADMS) Advisory Board 1994-2000.